Ch. 4 - MTI

- Moving Target Indicator;
- ~~Clutter Characterization~~;
- Doppler Filter Banks;
- Moving Platform Target Indicator.

4.1 MTI/Pulse-Doppler Radar

- Concept introduced during WWII;
- Signal processing technic developed since the decade of 1950-60;
- Digital processing led to the generalization of MTI;
- Essential in aerial surveillance in the presence of clutter;
- Air defense systems use separation techniques to distinguish moving targets from clutter.

4.1 MTI/Pulse-Doppler Radar

Doppler effect → Velocity measurement (CW)

Doppler effect → Target separation: Stationary (clutter)/Moving

MTI:

Without distance ambiguity;

With Doppler frequency ambiguity (blind speeds).

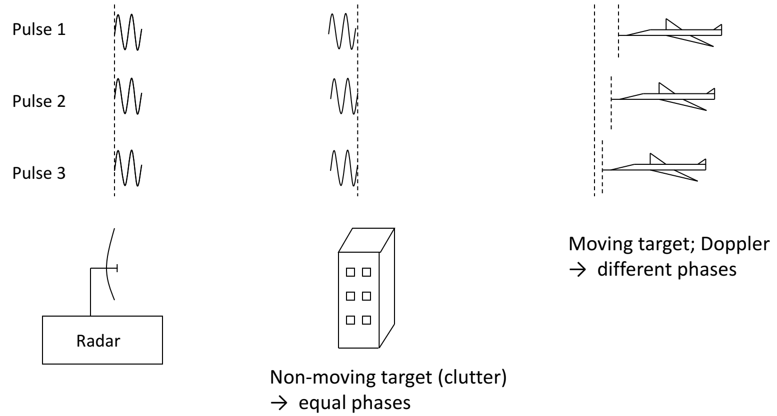
Pulse-Doppler:

Without Doppler frequency ambiguity;

With distance ambiguity.

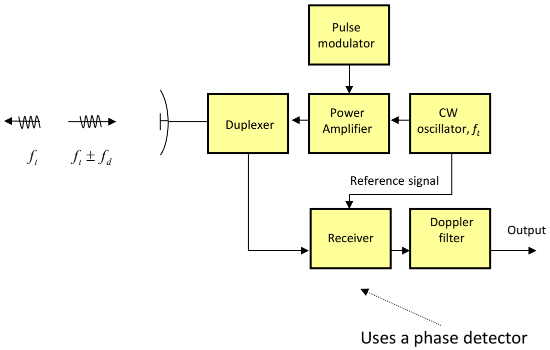
4.1 MTI/Pulse-Doppler Radar

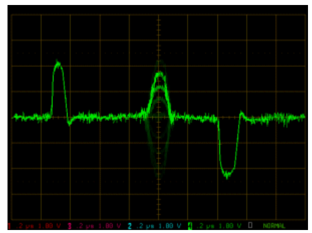
Returned phase in a pulse sequence



4.1 MTI/Pulse-Doppler Radar

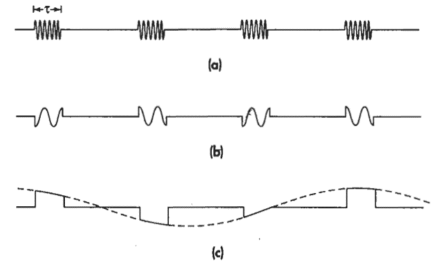
Doppler Frequency shift determination with a pulse radar





4.1 MTI/Pulse-Doppler Radar

Pulses at transmission and at the phase detector output of a Pulse-Doppler radar



a) Transmitted pulses;

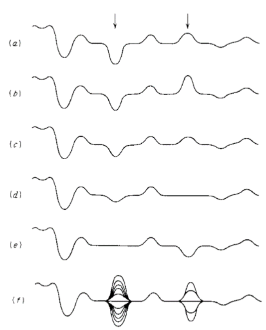
b) Detector output when $f_d > 1/\tau$ (rarely occurs);

c) Detector output when $f_d < 1/\tau$ (the output on a CW radar detector is also shown ---).

4.1 MTI/Pulse-Doppler Radar

A-scope radar returns observation

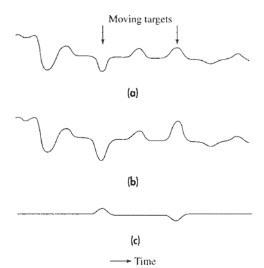
Butterfly effect



(a-e) Phase detector output of successive sweeps as seen on an A-scope display (arrows indicate moving targets).

(f) Super-imposed sweeps; "butterfly" effect

Clutter cancelation

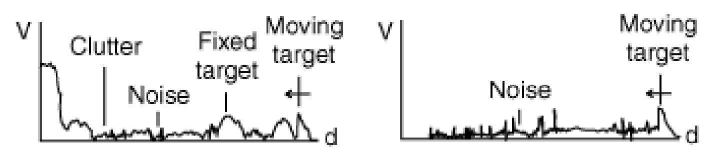


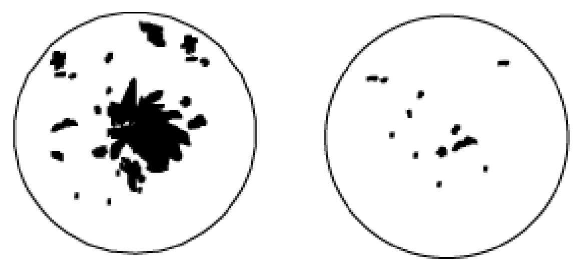
a) e b) Phase detector output successive sweeps as seen on an A-scope display.

c) Clutter cancellation by subtraction of a) and b).

4.1 MTI/Pulse-Doppler Radar

A-scope radar returns observation



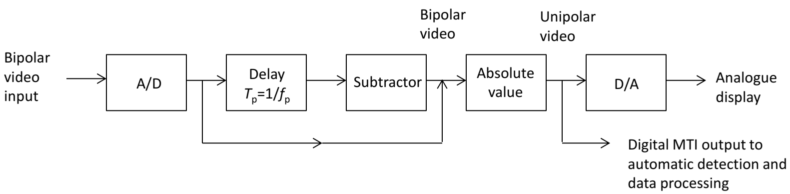


Without MTI

With MTI

4.1 MTI/Pulse-Doppler Radar

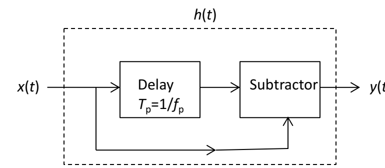
Clutter single canceller



Single canceller block diagram

4.1 MTI/Pulse-Doppler Radar

Single canceller frequency response



Response: $y(t) = x(t) - x(t - T_p)$

Impulse response: $h(t) = \delta(t) - \delta(t - T_p)$

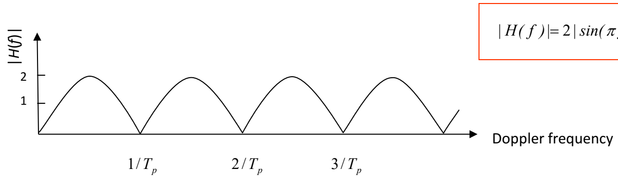
Transfer function: $H(f) = 1 - e^{-j2\pi f T_p}$ → $|H(f)| = 2|\sin(\pi f T_p)|$

$|H(f)|^2 = 4 \sin^2(\pi f T_p)$

4.1 MTI/Pulse-Doppler Radar

Single canceller frequency response

$$|H(f)| = 2|\sin(\pi f T_p)|$$



Single canceller filter frequency response

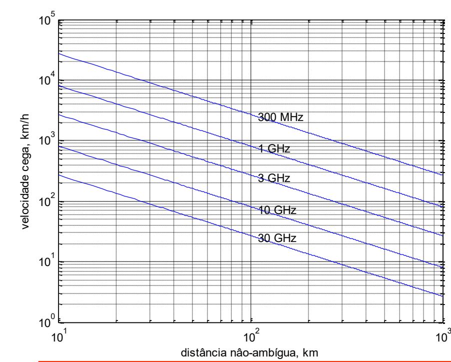
Blind speeds

$$v_n = \frac{n\lambda}{2T_p} = \frac{n\lambda f_p}{2} \quad n = 1,2,\ldots$$

$$f_d = \frac{2v_r}{\lambda} = \frac{n}{T_p} = nf_p \quad , \quad n = 0,1,2,\ldots$$

4.1 MTI/Pulse-Doppler Radar

Blind speed vs MUR

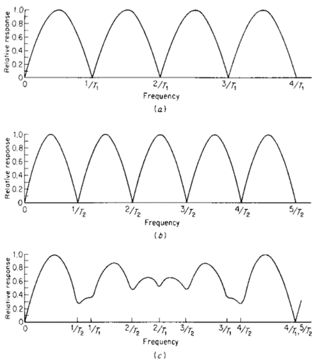


$$v_{b1} = \frac{\lambda f_p}{2} \qquad MUR = \frac{c}{2f_p} \qquad v_{b1} \times MUR = \frac{\lambda c}{4} = \frac{c^4}{4f}$$

Problems 4.1, 4.3 and 4.7

4.1 MTI/Pulse-Doppler Radar

Staggered pulses – Multiple PRT



a) Frequency response of a single line canceller for $f_p=1/T_1$;

b) The same for $f_p=1/T_2$;

c) Composed response with $T_1/T_2= 4/5$

4.1 MTI/Pulse-Doppler Radar

Staggered pulses– multiple PRT

- When staggered pulses are used with inter-pulse time periods such as

$$\frac{n_1}{T_1}=\frac{n_2}{T_2}=\ldots=\frac{n_N}{T_N}$$

- The first blind speed values

$$\frac{v_1}{v_B}=\frac{n_1+n_2+\ldots n_N}{N}$$

- where v_B corresponds to a fixed time between pulses equal to the average value $v_B=\frac{\lambda}{2\langle T\rangle}$, where $<T>=\frac{T_1+T_2+\ldots T_N}{N}$.

4.1 MTI/Pulse-Doppler Radar

Staggered pulses– multiple PRT

Example: 25 : 30 : 27 : 31;

Estimation of the first blind speed when $<T>$ = 1.33 ms and f = 1.5 GHz:

$$\frac{n_1}{T_1}=\frac{n_2}{T_2}=\frac{n_3}{T_3}=\frac{n_4}{T_4}=\frac{n_1+n_2+n_3+n_4}{T_1+T_2+T_3+T_4}=\frac{28.25}{<T>}$$

$$T_1=\frac{28.25}{25}<T>\rightarrow 1.17\ \text{ms}$$

$$T_2=\frac{28.25}{30}<T>\rightarrow 1.41\ \text{ms}$$

$$T_3=\frac{28.25}{27}<T>\rightarrow 1.27\ \text{ms}$$

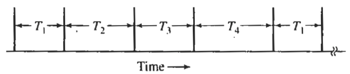
$$T_4=\frac{28.25}{31}<T>\rightarrow 1.45\ \text{ms}$$

4.1 MTI/Pulse-Doppler Radar

Staggered pulses– multiple PRT

Example: 25 : 30 : 27 : 31;

Estimation of the first blind speed when <*T*> = 1.33 ms and *f* = 1.5 GHz:



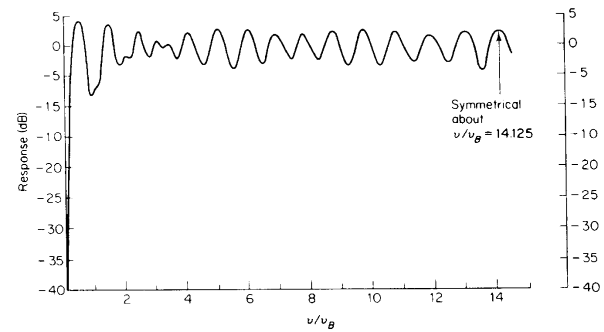
$$\frac{v_1}{v_B} = \frac{n_1 + n_2 + n_3 + n_4}{4} \rightarrow \frac{25 + 30 + 27 + 31}{4} = 28.25$$

$$v_B = \frac{\lambda}{2 \langle T \rangle} \rightarrow \frac{0.20}{2 \times 1.33 \times 10^{-3}} = 75\ \mathrm{m/s} \rightarrow 270\ \mathrm{km/h}$$

$$v_1 = 2118.75\ \mathrm{m/s}$$
$$= 7627.5\ \mathrm{km/h}\ (\mathrm{MaC}\ 6.23)$$

4.1 MTI/Pulse-Doppler Radar

Staggered pulses– multiple PRT

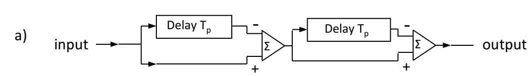


Example of frequency combined response to 5 staggered pulses (4 delay lines)

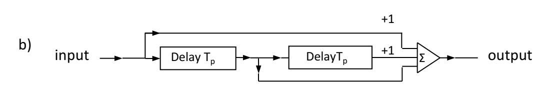
Problem 4.2

4.1 MTI/Pulse-Doppler Radar

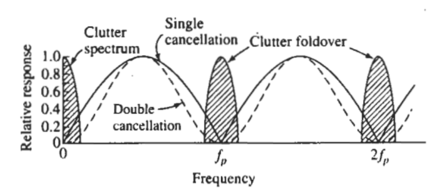
Comparison of single and double cancellers



Double canceller



Three-pulse canceller



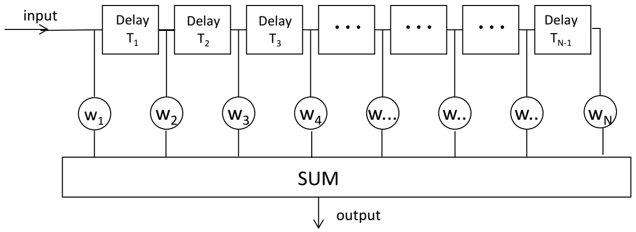
4.3 Doppler Filter Banks

- An ideal MTI filter should reject the DC clutter and PRF multiples;
- It should have a flat characteristic at all other frequencies in the band;
- The formatting of the frequency response depends on the number of pulses to be processed;
- Increasing the number of pulses leads to greater flexibility in the filter design;
- However, the number of pulses is limited by the scanning speed and of the antenna beamwidth;
- Besides, the (n-1) first pulses, in an n pulses canceller, do not give useful response.

4.3 Doppler Filter Banks

Non-recursive transverse filters

- Single and double cancellers do not guarantee the best MTI filter response;
- Other finite response filters (FIR) can be designed with more flexible transfer functions.

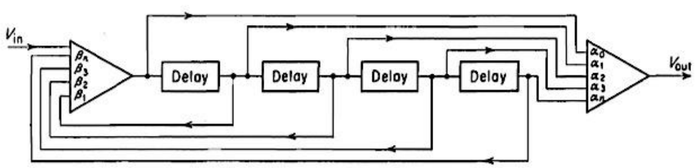


Canonical finite impulse response filter

4.3 Doppler Filter Banks

Feed-backward and feed-forward recursive filters

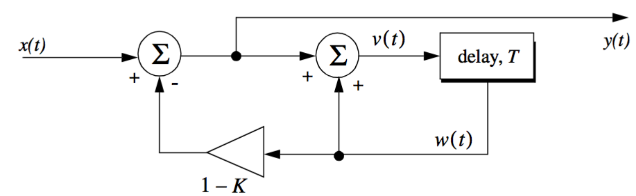
- More general filters with delays can be made with feed-back and feed-forward loops;
- These recursive filters (IIR – Infinite Impulse Response) have the following canonical configuration:



Canonical configuration

4.3 Doppler Filter Banks

Example of a recursive filter



$y(t) = x(t) - (1-K)w(t) \qquad v(t) = y(t) + w(t) \qquad w(t) = v(t-T)$

Using the Z transform with $z = e^{j2\pi fT}$

$Y(z) = X(z) - (1-K)W(z) \qquad V(z) = Y(z) + W(z) \qquad W(z) = z^{-1}V(z)$

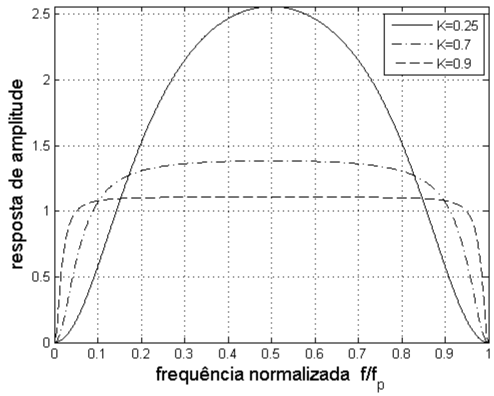
$$H(z) = \frac{1-z^{-1}}{1-Kz^{-1}}$$

$$z + z^{-1} = 2\cos(2\pi fT)$$

$$|H(e^{j2\pi fT})|^2 = \frac{2(1-\cos 2\pi fT)}{(1+K^2) - 2K\cos 2\pi fT}$$

4.3 Doppler Filter Banks

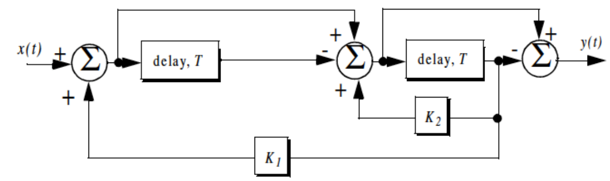
Example of a recursive filter



- Filter amplitude responses for different values of K (K = 0 reduces to a simple canceller);
- For higher values of K, filters are more flat, but to avoid time oscillations, the number of pulses should be of the order of $(1\text{-}K)^{-1}$;
- For instance, K=0.9 corresponds to 10 pulses.

4.3 Doppler Filter Banks

Another example of a recursive filter



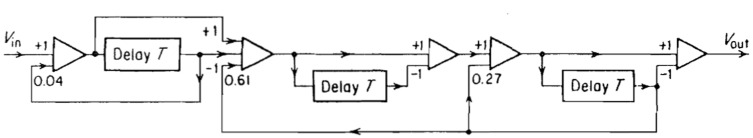
Using Z transform with $z = e^{j2\pi fT}$

$$H(z) = \frac{(z-1)^2}{k_1 - (k_1 + k_2)z + z^2}$$

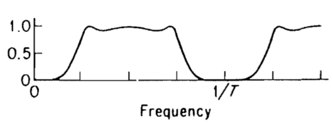
4.3 Doppler Filter Banks

Chebyshev filter

Example of a Chebyshev filter with 0.5 dB ripple in the pass band:



Transfer function:



Problem 4.8

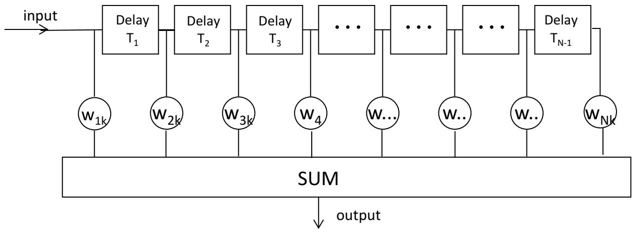
4.3 Doppler Filter Banks

Doppler filter bank

- Used to separate different targets;
- Improve the signal-to-noise ratio, increasing the detection sensitivity;
- Radial velocity determination (with ambiguity);
- Analogue alternative to FFT.

4.3 Doppler Filter Banks

FIR filter with (*N*-1) delay elements



Multiplier weights: $w_{ik} = e^{-j[2\pi(i-1)k/N]}$

k order filter: $i = 1,2,3\ldots N$ with $k \in [0, N-1]$

4.3 Doppler Filter Banks

Transfer function

- Filter consisting in *N* transverse filters, with weights

$$w_{i,k} = e^{j2\pi(i-1)k/N} \qquad i = 1,2 \ldots N \qquad k = 0,1 \ldots (N-1)$$

- Impulse response of filter *k*

$$h_k(t) = \sum_{i=1}^{N} \delta[t-(i-1)T_p]e^{j2\pi(i-1)k/N}$$

- Transfer function of filter *k*

$$H_k(f) = \sum_{i=1}^{N} e^{-j2\pi(i-1)(fT_p - k/N)}$$

4.3 Doppler Filter Banks

Transfer function

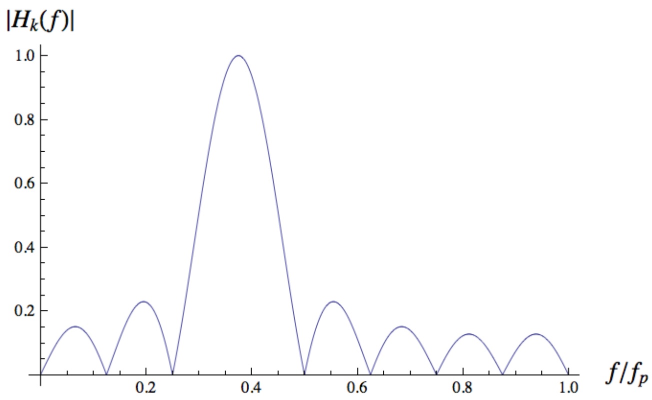
$$|H_k(f)| = \left|\sum_{i=1}^{N} e^{-j2\pi(i-1)(fT_p - k/N)}\right| = \left|\frac{\sin[\pi N(fT_p - k/N)]}{\sin[\pi(fT_p - k/N)]}\right|$$

- A selection algorithm collects the most intense output at contiguous filters allowing the determination of the approximate velocity of the detected target.

4.3 Doppler Filter Banks

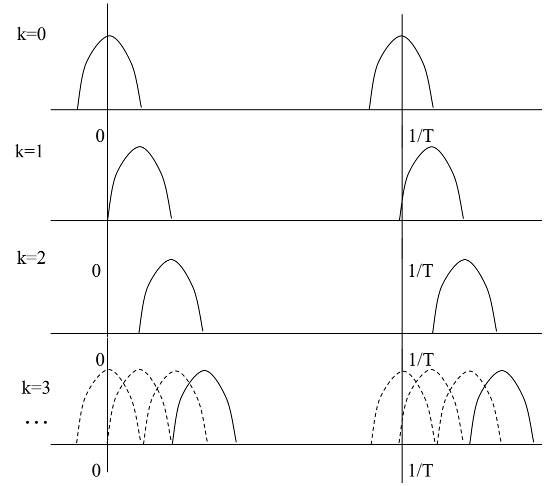
Transfer function

Example: N = 8, filter k = 3



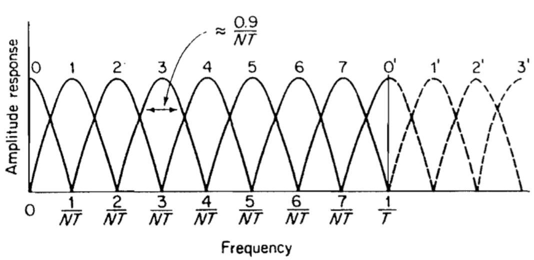
4.3 Doppler Filter Banks

Transfer function



4.3 Doppler Filter Banks

Transfer function

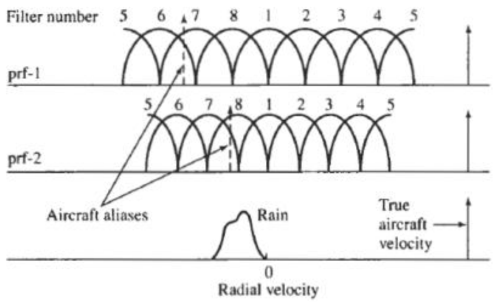


Problem 4.6

4.3 Doppler Filter Banks

Double PRF

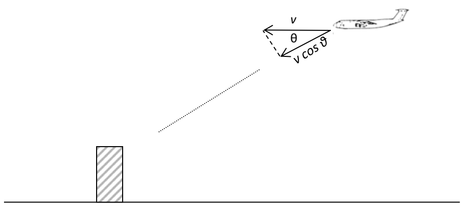
Distinguish targets affected by fold-over with one PRF



Detection of an aircraft in a rain cell using 2 PRFs and Doppler filters illustrating the aircraft visibility with PRF1, due to the Doppler "fold-over", being invisible due to rain overlay for PRF2

4.4 Moving Platform

AMTI – Airborne Moving Target Indicator



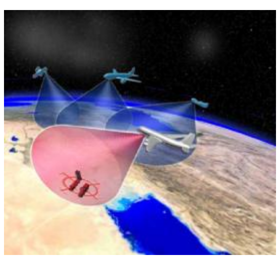
- Fixed target (clutter) originate Doppler effect;
- Doppler spectrum widens:

$$f_d = \frac{2v}{\lambda}\cos\theta \qquad \delta(f_d) = \frac{2v}{\lambda}\delta(\cos\theta)$$

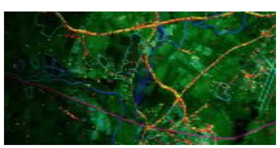
$$|\Delta f_d| = \left|\frac{2v}{\lambda}\sin\theta\right| \times |\Delta\theta|$$

4.4 Moving Platform

GMTI – Ground Moving Target Indicator



Used in Doppler MTI radar to distinguish between moving targets and surface clutter



It makes it possible to detect, locate and track land vehicles over a large area even in slow motion or in the sea surface.

Pulse-Doppler Radar

- Pulse-Doppler radar can use medium or very high PRF;
- The operating principle is similar to the MTI processing, but using higher PRF, with consequent increase of ambiguities in the frequency domain (blind speeds);
- A pulse-Doppler radar receives, in general, more clutter than an MTI radar, thus it requires a higher improvement factor for satisfactory operation.

4.4 Moving Platform

Airborne pulse-Doppler radar

Pulse-Doppler radars are used in airborne platforms, such as in AWACS (Airborne Warning and Control Systems)

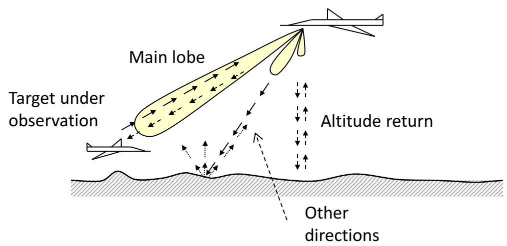
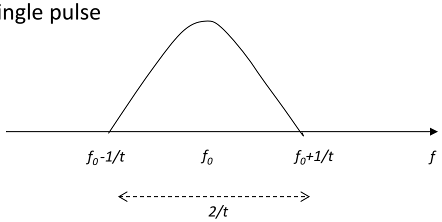


Figure illustrates the main lobe, the side lobe, and the clutter from ground.

4.4 Moving Platform

Airborne high PRF pulse-Doppler radar transmission spectrum

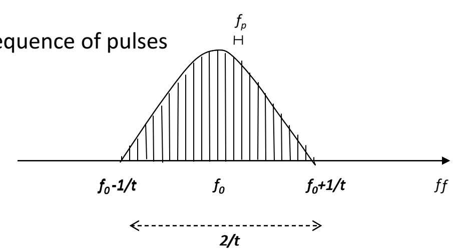
- Spectrum of a single pulse



4.4 Moving Platform

Airborne high PRF pulse-Doppler radar transmission spectrum

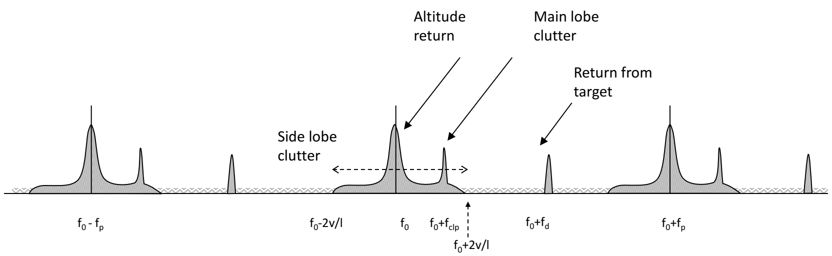
- Spectrum of sequence of pulses



- Spectrum of a periodic pulse sequence with high prf: $1/\tau \gg f_p$; (f_p= *prf*)
- The spectrum is centered at the oscillator frequency, and concentrates in a bandwidth $2/\tau$;
- The spectrum shows lines separated by the pulse repetition frequency f_p.

4.4 Moving Platform

Airborne high PRF pulse-Doppler radar received spectrum



f_0 Transmission frequency

f_d Doppler shift due to target (radar/target relative movement)

f_p Repetition frequency

v Platform velocity relative to ground

$2v/\lambda$ Side lobes clutter spreading

f_{clp} Main lobe clutter

Very high f_p allows larger separation between the spectral components identified in the figure.

Problem 4.12